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# DESIGN OF SERT II SPACECRAFT STRUCTURES

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16. Abstract

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## SUMMARY

The SERT II spacecraft structures are simple, rugged, low-cost structures that can be easily changed to adapt to new components. They were designed, fabricated, and vibration tested over a very short time span with minimal stress analysis since weight was not a problem. Both are constructed from riveted aluminum and magnesium sheet and are cylindrical semimonocoque-type structures. Simple, low-cost, easily designed and analyzed structures such as the SERT II structures may be used more often in the future when lower launch cost vehicles come into full use. The design constraints, design description, fabrication and handling, and shock and vibration testing of the SERT II structures are the subject of this report.

## INTRODUCTION

The SERT II mission is the second Space Electric Rocket Test. The SERT I mission was a suborbital test which demonstrated the ability of ion thrusters to develop thrust. The prime SERT II objective was to endurance test a mercury bombardment electric thruster for 6 months.

The orbital configuration of the SERT II satellite is shown in figure 1. It consists of the basic Agena D stage with the spacecraft-spacecraft support unit - electric rocket end facing the earth and the Agena rocket - solar array end away from the earth. Gravity-gradient stabilization is achieved by locating all the heavy masses at the ends of the satellite. The satellite was launched into a 1000-kilometer (540-n-m), near-polar circular orbit. The orbit was calculated so that the orbit plane of nodes would precess at a rate approximately equal to the earth's motion around the sun. Thus, the solar arrays will face the sun for almost the entire mission. (The SERT II mission is described in detail in ref. 1.)

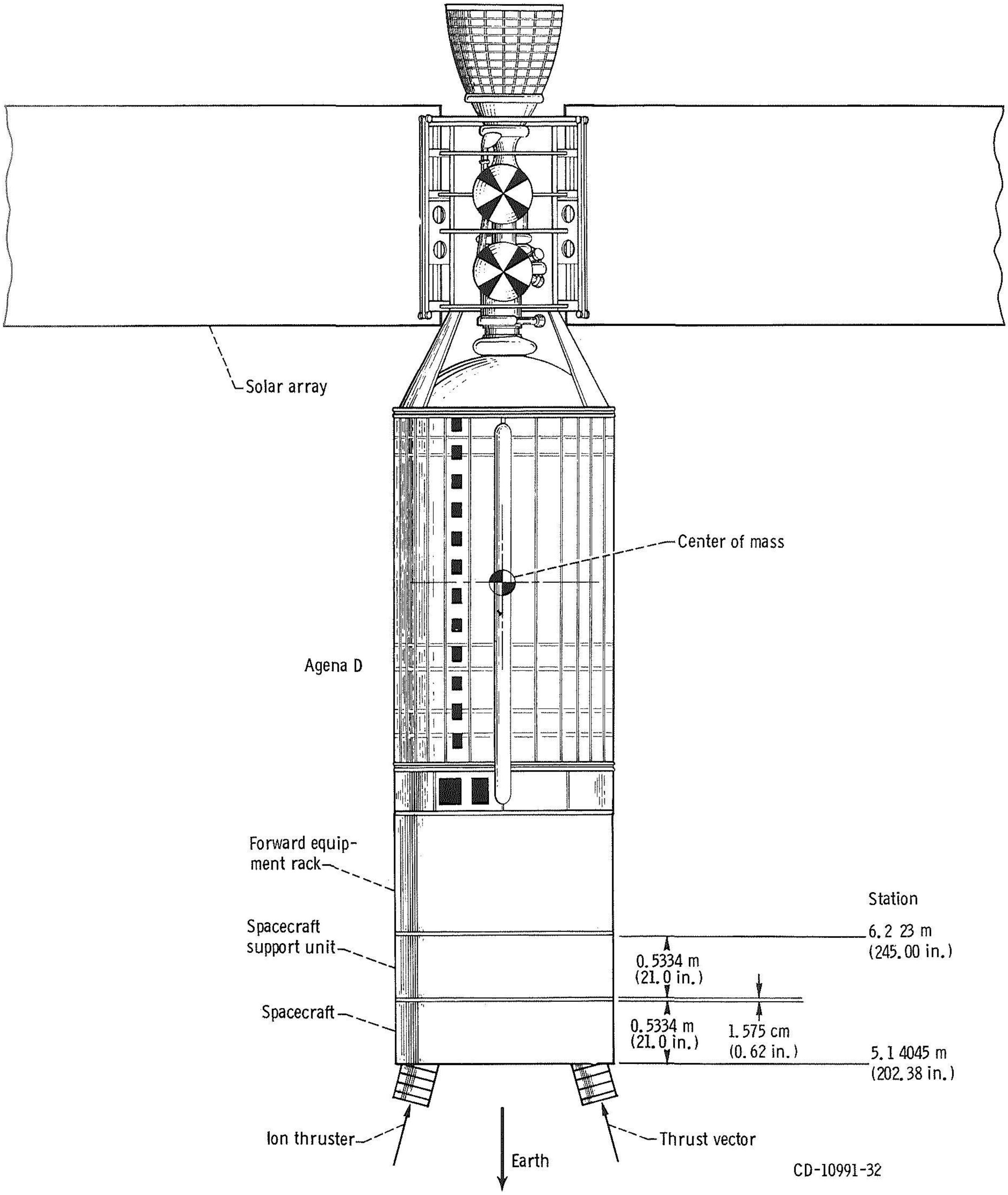



Figure 1. - SERT II satellite.

This report presents a discussion of the design constraints, design description, fabrication and handling, and shock and vibration testing of the SERT II spacecraft - spacecraft support unit structures.

The spacecraft (S/C) was designed and fabricated at NASA Lewis Research Center. The spacecraft support unit (SSU) was designed and one experimental model fabricated at NASA Lewis Research Center. Fairchild-Hiller Corporation also contributed to the spacecraft support unit structural analysis and fabricated the second experimental unit and the prototype and flight spacecraft support units.

## DESIGN REQUIREMENTS AND CONCEPTS

The designer of a spacecraft structure is required to devise a means of integrating all the mission-required components, experiments, and harnessing into a structure which will provide an environment through launch that will not exceed the mechanical dynamic capability of the total system. After launch, the structure must serve as a part of the thermal control system. Thus, the structure cannot be designed separately but must be an integral part of the overall spacecraft system.

The SERT II spacecraft system consisted of a spacecraft and a spacecraft support unit attached together (fig. 1). Both the S/C and SSU were required to maintain component mounting flexibility. The S/C and SSU had to be capable of accepting new components, or the deletion of redundant components, without disturbing the overall structural integrity of either the component or the structure.

The S/C structure was required to house all the experiments and their electronics. The SSU enclosed the housekeeping electronics and the control moment gyros. The configurations of both the S/C and the SSU were dictated by the required placement of the experiments and the control moment gyros. The ion thrusters had to be placed at the ends of the S/C on opposite sides so that the thrust vectors would point through the satellite center of mass and prevent tumbling, as shown in figures 1 and 2. The ion thruster power conditioning had to be mounted on an outer wall facing away from the sun so that the excess heat could be rejected, as shown in figure 3. A large gas supply for the backup attitude control system was also required (see fig. 3). A four-cross-beam configuration was selected to house these elements, with the ion thrusters mounted on opposite outer bays, the power conditioning mounted on the outer skin of a shade-facing outer bay, and the gas supply mounted in the central bay. The electronics for the experiments were then mounted on the sun-side outer bays of the spacecraft, as shown in figures 3 and 4.

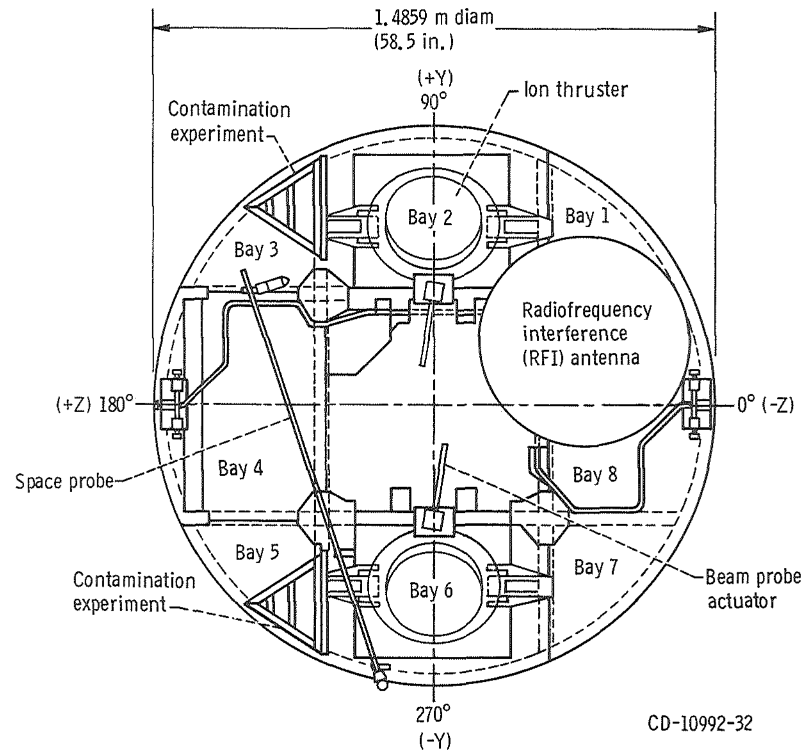



Figure 2. - Top view of spacecraft.

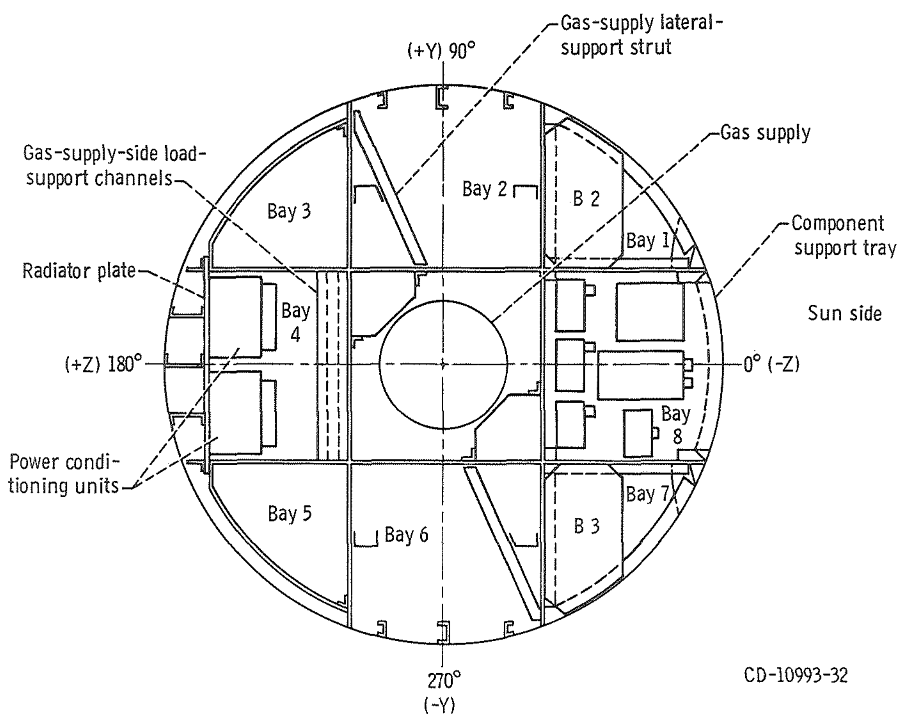



Figure 3. - Spacecraft top tray.

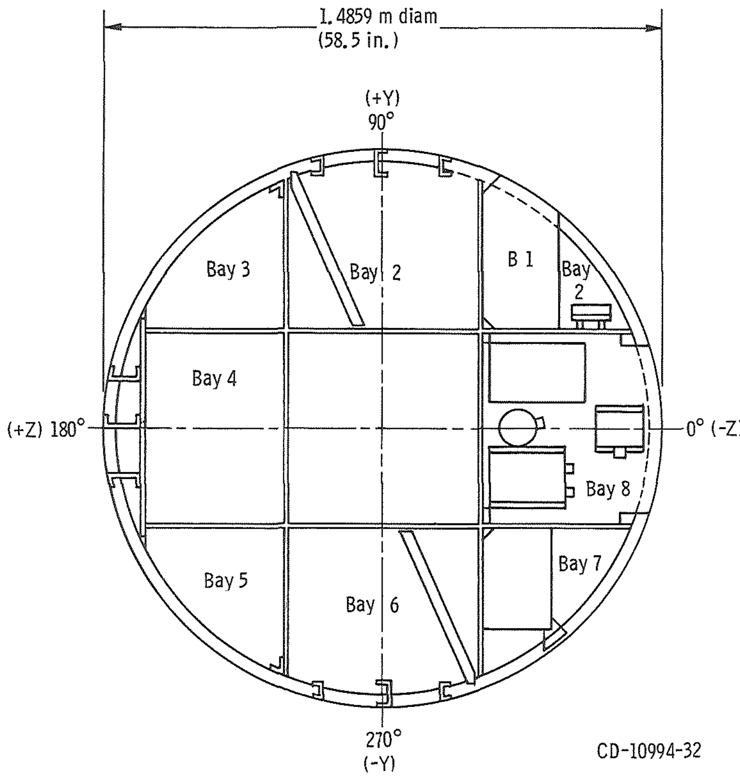



Figure 4. - Spacecraft bottom tray.

A four-cross-beam configuration was also selected for the SSU structure so that the control moment gyros could be properly alined with the orbital configuration principal axes by mounting them in the central bay, as shown in figures 5 and 6. The housekeeping electronics were then positioned on trays in the outer bays. Riveted aluminum and magnesium, cylindrical, semimonocoque, sheet-metal-type structures were selected for both the S/C and the SSU.

The SERT II spacecraft structures succeeded in achieving the design goals of simplicity, ruggedness, low cost, and adaptability to changing components. They were developed on a tight schedule with minimized stress analysis since low structural weight was not critical. The Agena had reserve weight-orbiting capability and the extra weight was desired for gravity-gradient stabilization.

Experimental S/C and SSU structures were loaded with mass dummies of the electronics components and experiments and extensively vibration and shock tested. One experimental spacecraft structural assembly was even used as a vibration qualification test bed. Only two minor fatigue failures occurred with this experimental structure during all this testing and no vibration fatigue failures were noted in either the prototype or flight assemblies.

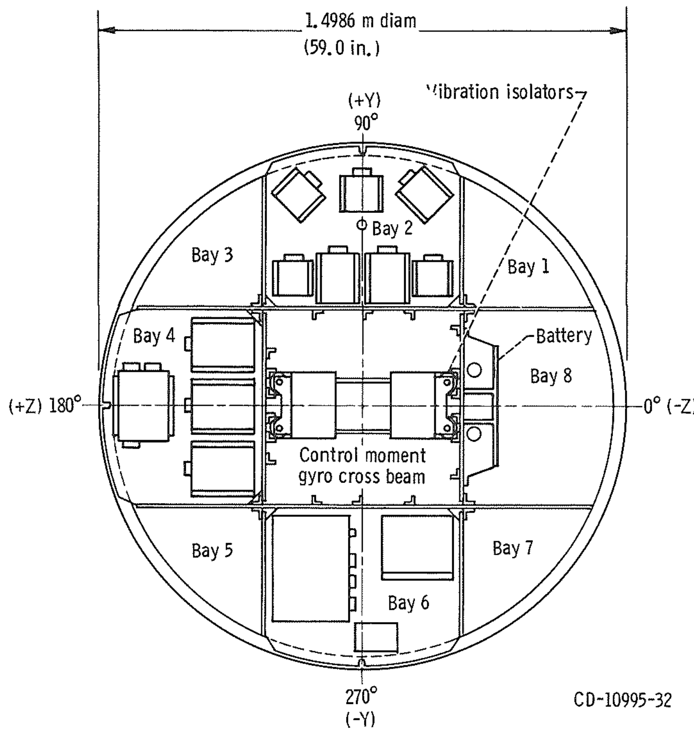



Figure 5. - Spacecraft support unit top tray.

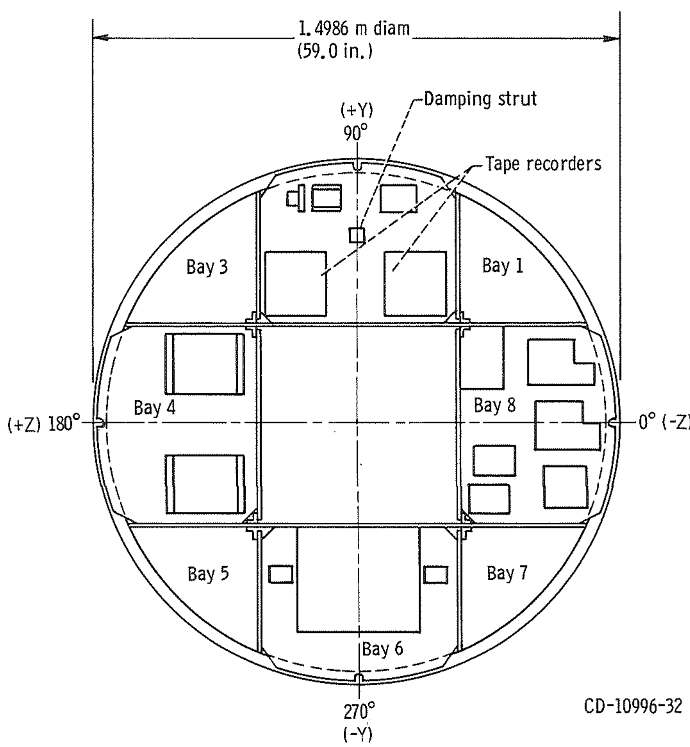



Figure 6. - Spacecraft support unit bottom tray.

# DESIGN CONSTRAINTS

## Mechanical Envelope and Interfaces

The S/C-SSU was designed to be launched on a Thorad-Agena D and therefore had to be compatible with the dynamic envelope of the 1.6510-meter- (65-in.-) outside-diameter standard Agena clamshell (SAC) shroud, as shown in table I.

TABLE I. - STANDARD AGENA CLAMSHELL

SHROUD DYNAMIC ENVELOPE

| Vehicle station | | Dynamic envelope diameter | | | |
|---|---|---|---|---|---|
| | | Z-Z axis | | Remainder of circumference | |
| m | in. | m | in. | m | in. |
| 4.95618 | 195.125 | 1.51478 | 59.637 | 1.51808 | 59.767 |
| 5.68008 | 223.625 | 1.52410 | 60.004 | 1.53096 | 60.274 |
| 6.23300 | 245.00 | 1.52756 | 60.140 | 1.53670 | 60.500 |

## Vibration and Acceleration Loads

The spacecraft was designed to accept at its base in each axis a sinusoidal vibration of 7.5 g's, combined with a random acceleration of 4.8 g's. These unamplified vibration inputs were per the NASA Agena D Mission Capabilities Restraints Catalog (ref. 1). The resonant cross-beam vibration and amplification factors used to multiply the sine and random vibration inputs for the cross-beam stress analysis were 5 and 2, respectively, and were predicted from past experience on other projects. The cross-beam first-mode natural frequency was also required to be greater than 200 hertz in order to avoid coupling with component resonances. The oscillatory loads were used with a safety factor of 2 on elastic buckling or yield to arrive at the initial design configuration. The steady-state accelerations were not included as design loads since they were much smaller than the qualification test input loads and these inputs were at least 1.5 times flight levels. The initial design was then modified as needed to meet the vibration resonance and thermal conduction requirements of the various components.

The masses used to compute the spacecraft design loads are given in table II.

TABLE II. - ASSUMED SPACECRAFT DESIGN MASSES

| Stem | Bay | Location of center of mass | | | | | Design load | |
|---|---|---|---|---|---|---|---|---|
| | | Station | | Angle, deg. | Radius | | | |
| | | m | in. | | m | in. | kg | lb |
| Thruster system 1 | 2 | 5.1562 | 203 | 90 | 0.508 | 20 | 34.02 | 75 |
| Thruster system 2 | 6 | 5.1562 | 203 | 270 | .508 | 20 | 34.02 | 75 |
| Backup attitude control system | Center | 5.4102 | 213 | --- | 0 | 0 | 46.27 | 102 |
| Power conditioner 1 | 4 | 5.4102 | 213 | 170 | .6604 | 26 | 8.16 | 18 |
| Power conditioner 2 | 4 | 5.4102 | 213 | 190 | .6604 | 26 | 8.16 | 18 |
| Tray | 1 | 5.588 | 220 | 45 | .508 | 20 | 20.87 | 46 |
| | 1 | 5.3086 | 209 | 45 | | | 20.87 | 16 |
| | 8 | 5.588 | 220 | 0 | | | 7.26 | |
| | 8 | 5.3086 | 209 | 0 | | | | |
| | 7 | 5.588 | 220 | 315 | | | | |
| | 7 | 5.3086 | 209 | 315 | | | | |
| | 3 | 5.3086 | 209 | 135 | | | | |
| | 5 | 5.3086 | 209 | 225 | | | | |
| Structure | ------ | ------ | --- | --- | ----- | --- | 67.59 | 149 |
| Total design load | | | | | | | 283.5 | 625 |

A set of loading conditions different from those for the S/C were used to design the SSU since it was designed at a later time to survive an updated test specification. The SSU was configured to survive an ultimate vertical load applied by the spacecraft of 4082 kilograms (9000 lb). The vertical load was applied simultaneously with a shear from the S/C of 2858 kilograms (6300 lb) and a moment from the S/C of 12824 newton-meters (113 500 in.-lb), all at the S/C-SSU interface. This translated into a 15-g vertical steady-state acceleration applied simultaneously with a 10.5-g lateral steady-state acceleration, all by a S/C weight of 272 kilograms (600 lb). The loading effects of the 227-kilogram (500-lb) SSU on itself at these accelerations were also used as part of the ultimate loads. These steady-state acceleration loading conditions equal those test conditions suggested by the Goddard Space Flight Center (ref. 3).

The load-carrying ability of the SSU could be substantially increased, if required, by designing it with thicker outside skins or by changing the material of the outside skins.

## Thermal Design Constraints

The spacecraft and SSU cross beams were required to conduct heat from the sun side of the spacecraft to the shade side since the thermal control system was wholly passive. The design of the spacecraft power conditioning radiator plate was also determined by thermal conduction requirements. All exterior skin panels were required to have some type of thermal coating and in some instances these requirements determined the type of material.

## Design Philosophy

The SERT II spacecraft and spacecraft support unit structures were designed to be simple, low in cost, rugged, and readily adaptable to changing components. They were developed on a tight schedule with minimized stress analysis since weight was not a problem at the start of the program because the anticipated spacecraft weight was far below the launch vehicle's capability. Later in the program when weight did become a problem, the structural weight of the S/C was cut mostly by eliminating parts and using slightly more sophisticated fabrication techniques. For example, sheets with bent-up ends were used as cross-beam webs, instead of flat sheets with separate angle brackets at the ends, for attachments to other cross beams and outside curved sheets.

A high level of structural integrity was required to maximize the probability of achieving qualification without need for modification. The experimental structure was required to act as a vibration fixture for many full-scale vibration and shock qualifications tests.

# DESIGN DESCRIPTION

## General Analytical Procedure

The general analytical procedure was to treat both the S/C and SSU as nonbuckling semimonocoque cylinders; that is, the curved exterior panels, longerons, and stiffening rings were designed to accept the cross-beam thrust loads and shear loads without local buckling. The cross beams were designed to be web shear resistant (nonbuckling) with vertical stiffeners. Shear loads around cutouts were carried by doublers. Local cross-beam side loads, such as the loads from the S/C gas supply (fig. 3), were generally transmitted to the outer rings by the trays or other web stiffeners as shown in bays 2, 6, and 8 of the S/C (fig. 3). Where this was not possible, the local cross-beam side loads were transmitted to the beam intersections by local stiffeners as in bay 4 of the S/C (fig. 3). The procedures and formulas outlined in reference 4 were used to design in accordance with the loading system just described.

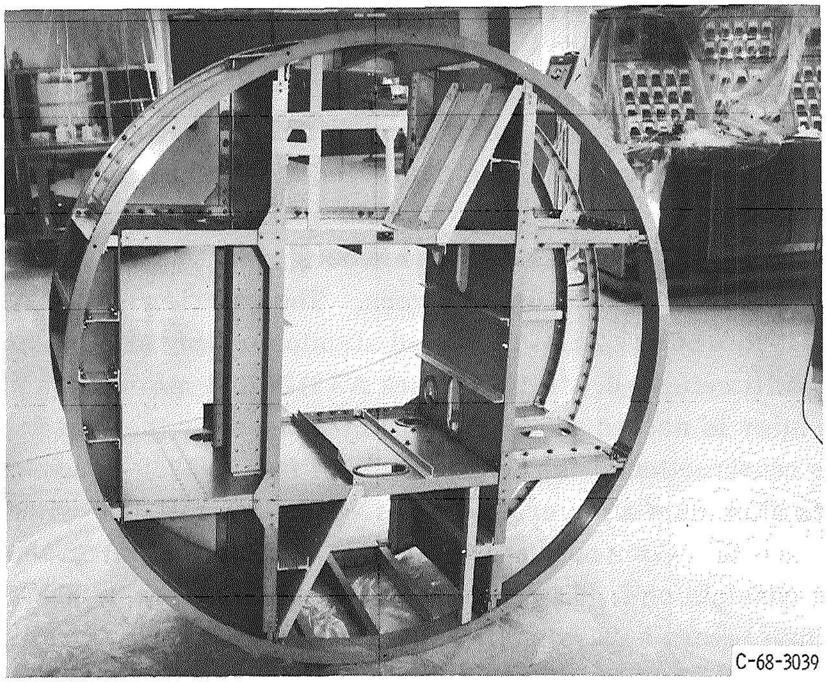
## Spacecraft General Construction

The exterior of the spacecraft is cylindrical and 0.5334 meter (21.0 in.) high by 1.4859 meter (58.5 in.) in diameter. The height was established by the requirement for two layers of component trays. The exterior construction for bays 1, 7, and 8 is semimonocoque, utilizing the 3.175-millimeter- (0.12-in.-) thick 6061-T6 aluminum alloy upper angle and lower channel rings and the 3.175-millimeter- (0.12-in.) thick AZ31B-H24 magnesium alloy outer tray support angles as ring members. The 6061-T6 aluminum alloy cross-beam ends are used as longerons (see figs. 2 to 4, and 7). The exterior skins are 1.016-millimeter- (0.040-in.-) thick 2024-T3 Alclad aluminum alloy sheet for bays 1, 7, and 8, where aluminum is needed because Z-93 paint is used as a thermal coating. AZ31B-H24 magnesium alloy sheet 0.8128-millimeter- (0.032-in.-) thick is used for the bay 2 and bay 6 skins, where Z-93 is not required. The 0.8128-millimeter- (0.032-in.-) thick 6061-T6 aluminum alloy sheet exterior skin construction of bays 3 and 5 and the 4.7752-millimeter- (0.188-in.-) thick 2024-T3 aluminum alloy plate exterior construction of bay 4 are designed to accept the ion thruster power conditioning units and radiate their accompanying high heat loads.

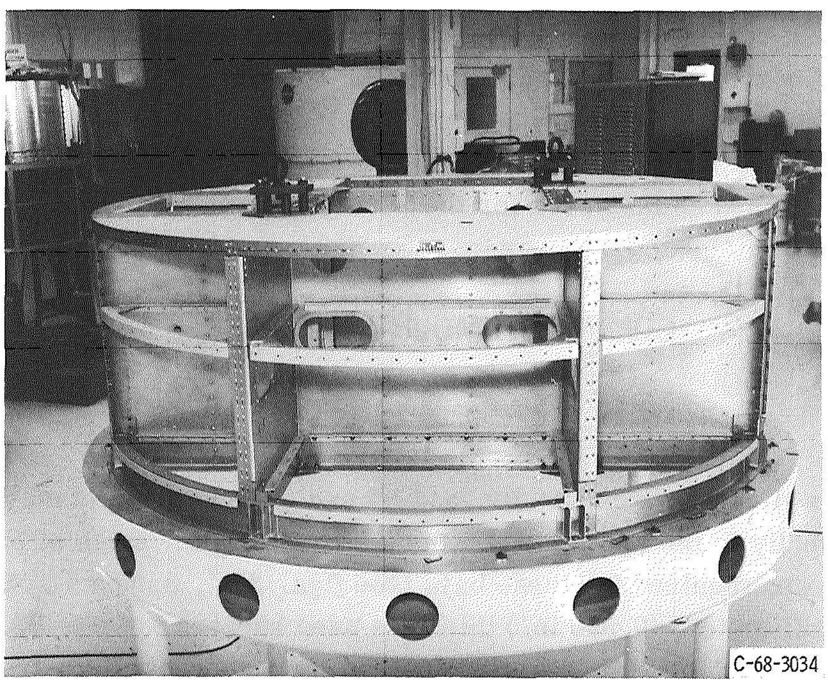
The interior construction consists of four 1.5748-millimeter- (0.062-in.-) thick 6061-T6 aluminum alloy cross beams which separate the cylinder into nine compartments or bays. This four-cross-beam general layout is similar to the Gemini-Agena target vehicle auxiliary rack. The auxiliary rack, however, has components mounted as cantilevers off the magnesium cross beams, which results in a high order of vibration amplification. To alleviate this problem, the SERT II spacecraft is designed to have the components mounted on AZ31B-H24 magnesium alloy waffle-plate trays which attach by means of magnesium angles to the cross beams and the exterior skins for the top tray layer and to the cross beams and the lower ring for the lower tray layer, as shown in figures 7(b) and 8.

Rivets of 2117-T4 aluminum alloy are used as general cross-beam shear fasteners. The countersunk screws used in the interior are $586\times10^6$-newton-per-square-meter (85 000-psi) ultimate strength, corrosion resisting steel. Skin screws are $862\times10^6$-newton-per-square-meter (125 000-psi) ultimate strength, corrosion resisting steel.

The S/C structure as here described represented 24 percent of the total flight S/C weight.




(a) Bottom view.




(b) Bay 8 side.

Figure 7. - Spacecraft structure.

## Spacecraft Support Unit General Construction

Like the spacecraft, the exterior of the SSU is cylindrical and 0.5334 meter (21.0 in.) high to accommodate two layers of trays. However, it is 1.4986 meters (59.0 in.) in diameter instead of 1.4859 meters (58.5 in.) in order to have the S/C-SSU and SSU-Agena attaching bolt circles be interior to the SSU outside skins. The exterior construction is semimonocoque, utilizing the forged 3.175-millimeter- (0.12-in.) thick 6061-T6 aluminum alloy upper angle and lower channel rings and the 6061-T6 aluminum alloy tray support angles as ring members and the ZK60A-T5 magnesium alloy posts at the cross-beam ends as longerons. The exterior skins are 1.016-millimeter- (0.040-in.-) thick 2024-T3 Alclad aluminum alloy sheet for bays 1, 7, and 8 and 1.016-millimeter- (0.040-in.-) thick AZ31B-H24 magnesium alloy for bays 2 to 6. Aluminum alloy is needed where Z-93 paint is used for thermal control purposes.

The interior construction of the SSU consists of four 1.5748-millimeter- (0.062-in.-) thick aluminum alloy cross-beams which separate the cylinder into nine bays (see figs. 5 and 6). Components are mounted on trays of Barry, Inc., elastomeric Rigidamp, which consists of 1.8034-millimeter- (0.071-in.-) thick 2024-T3 aluminum alloy top and bottom layers separated by an elastomeric dynamic damping compound. The lower trays are attached in bays 2, 4, 6, and 8 by means of 2.032-millimeter- (0.080-in.-) thick 6061-T6 aluminum alloy angles to the cross beams and directly to the lower ring. In bays 2, 4, and 6, the upper trays are attached to the cross beams and the outer skins by means of 2.032-millimeter- (0.080-in.-) thick 6061-T6 aluminum alloy angles. There is no upper bay 8 tray.

The same general type of aluminum alloy rivets and stainless-steel screws used in the spacecraft are used as fasteners for the SSU.

# COMPONENT MOUNTING FEATURES

## Spacecraft

The power-switching boxes B1, B2, and B3 and the A1 temperature-measuring box are mounted directly to the spacecraft on the upper and lower levels of bays 1 and 7 and, thus, no trays were required for these bays (see figs. 3, 4, 8, and 9). Butyl rubber gaskets 1.524 millimeters (0.060 in.) thick are used between the B1, B2, and B3 boxes and their mounting surfaces for vibration attenuation purposes. High-frequency amplifications were four to one when the holddown bolts were torqued to their normal torque. The two ion thruster systems are mounted to gimbal support systems which, in turn,

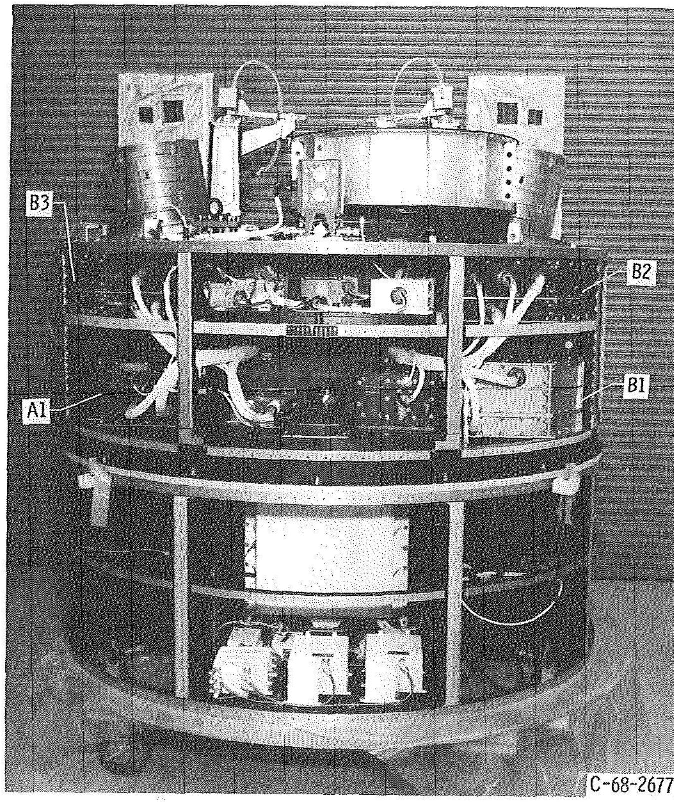


Figure 8. - Spacecraft and spacecraft support unit component mounting.

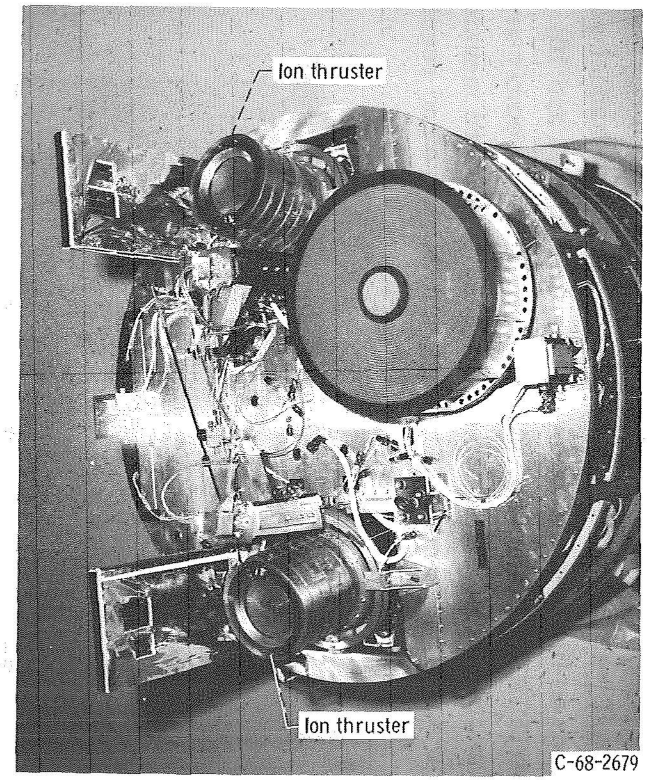


Figure 9. - Component mounting to top of spacecraft.

are mounted directly to the spacecraft in bays 2 and 6 (see figs. 2, 3, and 9). Substructure carries the thruster dynamic loads to the Y-Y axis cross beams. Both power conditioning units (PCU) are mounted to the bay 4 thermal radiator plate, which is the bay 4 outside spacecraft wall. Exterior machined magnesium channel sections transmit the PCU dynamic loads to the spacecraft lower ring (see figs. 3 and 10). The backup attitude control system (BACS) tank and valve and regulator assembly are mounted in the central bay of the spacecraft. The two nozzle assemblies are mounted directly to the spacecraft top face at bays 4 and 8. The tank and the valve and regulator assembly

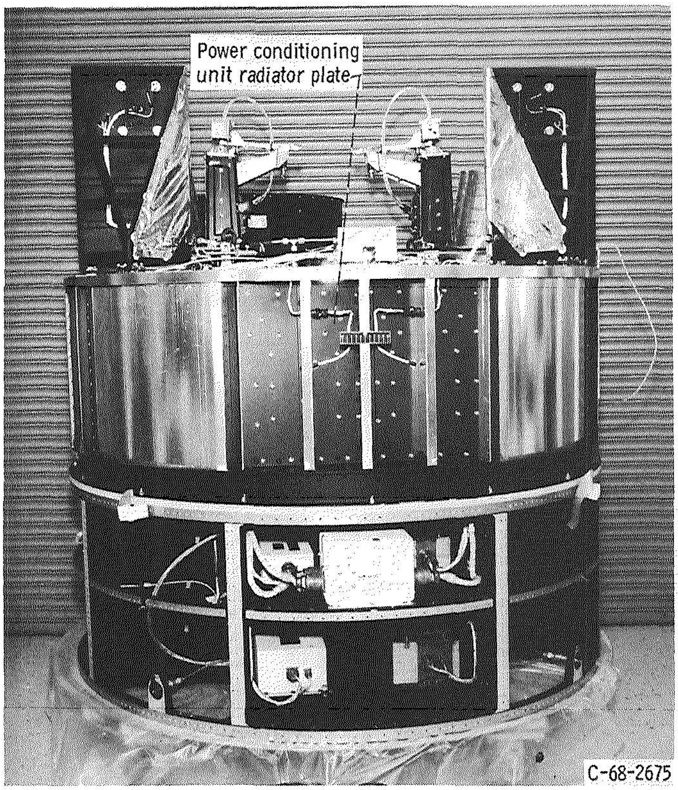



Figure 10. - Spacecraft and spacecraft support unit mounting.

are supported by brackets which attach to the cross beams of the spacecraft. The RFI (radiofrequency interference) antenna and contamination experiments are mounted directly to the cross beam and outer ring on the face of the spacecraft. All other experiment and electronics boxes are mounted to the upper and lower bay 8 instrument mounting trays.

## Spacecraft Support Unit

All instrumentation is mounted in bays 2, 4, 6, and 8 or the central bay. Only the antennas are mounted in the odd-numbered bays 1, 3, 5, and 7. The specific electronic box locations are detailed on figures 5 and 6. All electronic and electrical boxes except the battery and the control moment gyros (CMG's) are mounted on Rigidamp trays.

The battery was added after the basic configururation of the SSU had been established, and was too large for any instrument tray. The battery selected also has a very limited temperature range. It is therefore located on the sun side of the SSU and cantilevered from a well-reinforced, bay 8 back cross-beam wall.

The tape recorders located on the lower bay 2 instrument tray require that the tray vibration environment not exceed the rather low tape recorder qualification specification. To attenuate vibration to the tape recorders, the lower bay 2 tray was coupled to the upper tray in that bay. The coupling was accomplished by tying the two trays together with an aluminum tube surmounted with a Lord Manufacturing Company vibration isolator. The resultant two-body system has a lower tray vibration environment that meets the tape recorder specification requirements.

The CMG's have a very restrictive vibration environment qualification level. It was necessary to vibration isolate the four CMG's in order to meet these levels. This was accomplished by bolting the gyros to a box beam assembly and then vibration isolating

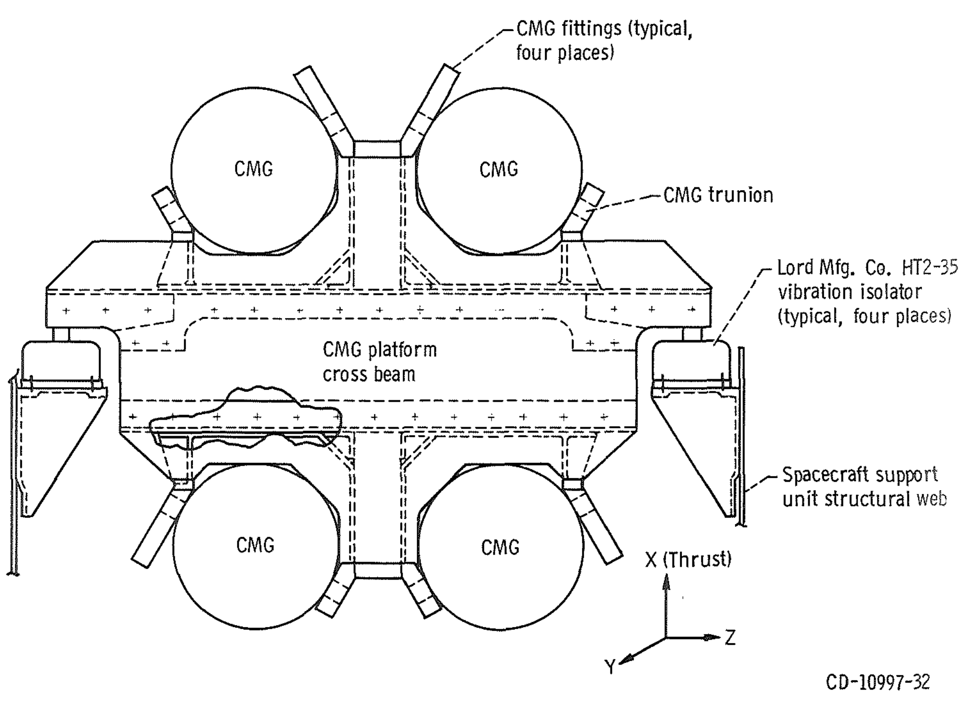



Figure 11. - Control moment gyro (CMG) cross-beam assembly.

the assembly, which is shown schematically in figure 11. It was essential that the CMG isolator beam assembly be resonant free to about 700 hertz in order to finally meet the CMG vibration requirements.

# FABRICATION AND HANDLING

## Fabrication

Briefly, the structural assembly procedure for both the spacecraft and SSU was to prepilot drill most detail parts, use clamps to position parts for transfer drilling of the rivet and bolt holes, and use Cleco temporary fasteners to hold alinement until all parts had been assembled. The entire spacecraft or SSU was then disassembled and the individual parts deburred, cleaned, and surface treated. All parts were then reassembled in a "gray" clean area using the specified rivets and bolts. The entire spacecraft assembly was then ultrasonically cleaned and baked to boil off residual liquids prior to application of thermal coatings.

## Surface Treatment

Both the spacecraft and the SSU specify the use of iridite 14.2 per MIL-C-5541A, type 1, grade C, class 3 for all aluminum alloy parts and Dow 17 per MIL-M-45202A, type 1, class C, 0.0025- to 0.0076-millimeter- (0.1- to 0.3-mil-) thick for all magnesium parts. These surface treatments were applied to the detail parts after all holes had been drilled to the final size but before final assembly of the individual parts.

## Handling

The spacecraft, the SSU, or the assembled S/C-SSU can be lifted vertically using a lifting beam assembly. The lifting beam assembly consisted of a beam with a central ring for attachment to the hoist and two vertical cables at the ends of the beam with rings on the ends of the cables. The cables were spaced the same distance apart as the diagonal distance to the spacecraft or SSU cross-beam intersections. Lifting adapters mated the lifting beam cable ends to the doublers at the cross-beam intersections.

A tip-over fixture assembly was used with a roll-over fixture to tip the S/C-SSU assembly horizontally and place it in a cradle where it could be rolled $360^{\circ}$ with its cylindrical axis parallel to the floor. These fixtures were fastened to the S/C-SSU by means of a compressive cradle ring at the top of the spacecraft and a base ring bolted to the bottom of the SSU lower ring.

The S/C-SSU assembly was also designed so that it could be hung in a vacuum chamber in the horizontal position. This was done by means of eight lugs which were fastened to the SSU, bay 4, cross-beam ends and the spacecraft, bay 4, cornerposts.

A horizontal handling fixture was used to mate the S/C-SSU to the Agena in a horizontal position. It utilized part of the tip-over fixture and two of the SSU, bay 4, lugs to perform this function.

## SHOCK AND VIBRATION TESTING

Four S/C and SSU structures were built. They were used for an experimental thermal-vacuum test model, an experimental mass dummy vibration test model, a prototype S/C-SSU, and a flight S/C-SSU.

The experimental mass dummy vibration test model was used first for vibration and shock qualification testing of the structure while it was loaded with mass dummies of the components. The levels finally selected for sine and random vibration qualification are given in table III. For shock testing, the experimental mass dummy S/C-SSU was subjected to three half-sine pulses of plus and minus 10 g's (±2 g's) peak amplitude for a duration of 8 milliseconds in the thrust (X) axis and plus and minus 9 g's (±2 g's) in the lateral ( Y and Z) axes.

After the initial vibration and shock qualification test, the experimental mass dummy S/C-SSU was subsequently used as a vibration test bed for 16 complete qualification level vibration and shock tests of other components. It was also used for many 1-g input sine vibration surveys and many other flight level (two-thirds of qualification vibration levels) acceptance tests of components. During all this testing, only two fatigue failures of substructure occured and these were easily repaired. The only other work done during this period was occasional tightening of all structural nuts and bolts.

The prototype S/C-SSU structure successfully completed its qualification vibration and shock test and later in the program the flight S/C-SSU structure successfully completed its flight level acceptance vibration and shock tests.

In general, the S/C-SSU structure behaved as a well-Coloumb-frictionally-damped structure should, with most of the damping occurring at the structural joints. The amplification on the cross beams to sine exitation was generally less than 2 when vibrated sinusoidally along the thrust axis. The peak resonance amplification of the component mounting trays on the flight S/C-SSU was less than 10 and averaged about 3.

TABLE III. - QUALIFICATION TESTS

(a) Sinusoidal sweep frequency qualification test[a]

| Axis | Frequency range, Hz | Acceleration | Sweep rate, octaves/min |
|---|---|---|---|
| Thrust (X) | 5 to 10 | 6.35 mm (0.25 in.) DA (double amplitude) | 2.0 |
| | 10 to 13 | 2.3 g's zero to peak | 2.0 |
| | 13 to 22 | 6.1 g's zero to peak | 1.0 |
| | 22 to 400 | 2.3 g's zero to peak | 2.0 |
| | 400 to 500 | Slope 2.3 to 4.5 g's | 2.0 |
| | 500 to 2000 | 4.5 g's zero to peak | 2.0 |
| Lateral (Y and Z) | 5 to 10 | 6.35 mm (0.25 in.) DA | 2.0 |
| | 10 to 250 | 1.5 g's zero to peak | ↓ |
| | 250 to 400 | 3 g's zero to peak | |
| | 400 to 500 | Slope 3.0 to 4.5 | |
| | 500 to 2000 | 4.5 g's zero to peak | |

(b) Random noise vibration qualification test[b]

| Frequency range, Hz | Acceleration level, g's rms | Spectral density, $g^2$/Hz |
|---|---|---|
| 20 to 400 | 3.32 | 0.03 |
| 400 to 2000 | 9.64 | .06 |

[a]Sweep time for 5 to 2000 Hz, ~4.3 min.
[b]Along each of the X, Y, and Z axes; duration, 4.5 min/axes; overall level, 10.2 g's rms.

# CONCLUSIONS AND RECOMMENDATIONS

The problem of spacecraft structural design is in reality the problem of packaging components and experiments so that they will survive the launch environment to function as a spacecraft system. This is the philosophy used in evolving the SERT II structures design. The spacecraft was designed within the weight, size, thermal, and economic considerations set forth at the program outset. This can be done for any S/C structure only if the design problem is considered as a system problem involving mechanical integration of all spacecraft experiments and systems. During initial design phases, design and fabrication complexities versus the possible benefits of a minimum-weight structure should be considered in view of the proposed launch vehicle. If no real benefits accrue, a great effort to design a minimum-weight structure can not be justified. For example, the cost of orbiting a payload using the proposed shuttle system could be more than an order of magnitude less than the cost for orbiting the same spacecraft using a rocket launch vehicle. If the shuttle vehicle were used, the most prudent course would be to build the spacecraft structure strong but simple without sacrificing efficiency and using inexpensive lightweight materials. A reasonable safety factor could then be used with a simple static analysis to design the spacecraft. The only time extensive structural analysis and exotic structural materials can be justified are

(1) When the structure is for the prime launch vehicle, such as a rocket vehicle or the shuttle itself

(2) When a lighter structure would permit another experiment to be placed on board

(3) If a more expensive rocket would be required were the spacecraft weight not trimmed

(4) If a less costly vehicle could be used if the structural weight were trimmed

When a new spacecraft is proposed, all systems should come under the same kind of scrutiny as proposed in the preceding paragraph. For instance, in the area of thermal control, heat pipes should not be used if solid conduction can be found to do the heat-transfer job at an acceptable weight increase. Electronics should be placed in boxes that are relatively heavy but simple and inexpensive to fabricate if the weight penalty is acceptable. Double and triple redundancy should be practiced in critical electronic areas if weight is no problem. The purpose of these steps is not to produce an inefficient spacecraft but to use weight margins so as to increase spacecraft reliability.

When the SERT II spacecraft was first proposed, many of these ideas were put into practice. This was desirable and possible because the launch vehicle was selected not only on a payload-to-orbit basis but mainly as a ready package that could adequately perform the SERT II mission. The second stage with its solar arrays at the rocket engine end was to become a large part of the orbiting vehicle. The SERT II S/C-SSU was launched successfully on February 2, 1970. Indications are that all components survived the launch environment undamaged. Thus, the choice of general configuration, materials, and construction techniques was validated for the SERT II structures.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, March 5, 1971,
704-13.

## REFERENCES

1. Goldman, Richard G.; Gursk, Guy S.; Hawersaat, William H.: Description of SERT II Spacecraft and Mission. NASA TMX-3087, 1970.

2. Anon.: NASA Agena D Mission Capability Restraints Catalog. Vol. 2. Tables 7-3, 7-4, and 7-5.

3. Anon.: General Environmental Test Specification for Spacecraft and Components Using Launch Environments Dictated by Atlas-Agena, Thor-Agena, or Thrust-Augmented Thor-Agena Vehicles. Specification S-320-A-1, NASA Goddard Space Flight Center, Oct. 1965.

4. Bruhn, E. F.: Analysis and Design of Flight Vehicle Structures. Tri-State Offset Co., 1965.



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